RESEARCH DEPARTMENT

Line-store standards conversion: the subjective effect of certain switch and store imperfections

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THE BRITISH BROADCASTING CORPORATION
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LINE-STORE STANDARDS CONVERSION: THE SUBJECTIVE EFFECT OF CERTAIN SWITCH AND STORE IMPERFECTIONS

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SUMMARY

The experiments described in this report were carried out in order to investigate the subjective effect of interference on a television display caused by variations in the transfer characteristics of the switches and storage devices in a line-store standards converter; these variations in the characteristics of switches and storage devices result in perturbations of the video signal which cause the picture to be impaired by vertical striations. Such impairments of the output of a line-store standards converter have been simulated by modulating a video signal, with reference to black level, using a 'perturbing' signal derived by scanning a specially prepared piece of film. Tests have been carried out in order to determine how the subjective effect of this form of impairment varies with its intensity.

By means of a theoretical analysis, the results of the subjective tests have been used to determine the subjective effects of impairments which would result if the perturbing signal were to modulate the video signal symmetrically about mid-grey level, and if the perturbing signal were added to the video signal.

1. INTRODUCTION

In a line-store standards converter,[1] the redistribution of the video information on a new time scale is carried out by means of a 'redistributing' store, which may contain a pair of electronic switches and a storage device for every picture-element position in one television line. The same pair of switches and storage device are used to process information in corresponding positions on all lines of the raster, so that any abnormal characteristic of a particular switch or store influences a vertical strip of the picture one element wide.

One difficulty encountered in designing a redistributing store is that a certain amount of variation in the transfer efficiencies* of the switches and storage devices cannot be avoided; the effect of these variations is to cause a corresponding modulation of the output signal from the converter. If no attempt is made to select

* The transfer efficiency of a pair of switches and the associated storage device is defined, in this report, as V_o/V_i where V_i is a change in the video signal, at the input to the redistributing store, corresponding to a given picture element and V_o is the change in the output video voltage which relates to the corresponding picture element at the output of the store.

or to dispose the switches according to their efficiencies, the modulation during any one line period varies in a random manner and is precisely repeated during all other line periods. The resulting subjective effect on a display of the output signal from the converter is that the displayed picture appears to have fixed vertical lines superimposed on it, the intensity of which vary randomly across the display.

Owing to the large amount of work involved in building a redistributing store, it is prudent, before building such a store, to determine the magnitude of variations in the switches and storage devices which would cause significant interference on a display of the output signal. A specification for the maximum tolerable variation in the transfer efficiencies of the switches and storage devices was therefore determined by simulating the type of interference that was expected and investigating the subjective effect of different levels of the interference.

The first part of this report describes the details of subjective tests in which this form of simulated interference was used. However, since these tests were carried out, further work on the design of switches and storage devices for use in a line-store standards converter has revealed that the actual interference resulting from variations in these switches and storage devices may differ in two ways from the simulated interference.

These two differences are due to:

(i) the use of a mid-grey instead of black level as the modulation reference level, and

(ii) the presence of a perturbing signal added to the output.

It has been found that, in order to obtain the maximum possible signal handling capacity from a given set of switches and storage devices, the capacitors used as storage devices should be discharged to mid-grey level by the 'read' switches, and not to black level (as had been assumed when the subjective tests were carried out). This difference, as illustrated in Fig. 1, has the effect of changing the modulation reference level from black level to mid-grey level; the figure shows the effect of the two types of modulation on a sawtooth video waveform. In addition to the variations in the characteristics of the switch and storage device which cause modulation of the video signal there also exist variations which result in the addition, to the output, of a perturbing signal of the same general form as the modulating signal. The effect of this added interfering signal on a sawtooth video waveform is illustrated in Fig. 2.

The subjective effects of modulating interference, with mid-grey level as reference, and added interference, can be deduced from the results of the subjective tests using modulation referred to black level. The calculations involved are given in the Appendix to this report and the results obtained are discussed in Section 4, which follows the description of the subjective tests.

2. DETAILS OF EXPERIMENT

2.1. Simulation of Modulating Signal

In order to simulate the modulation caused by the variations in the transfer efficiencies of the switches and storage devices it was necessary to modulate a video

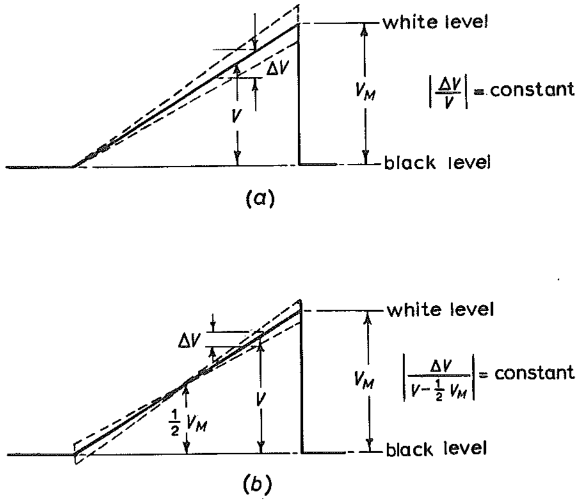

Fig. 1 - Effect of interference modulating a sawtooth video signal

(a) Simulated modulation with black level as reference

(b) Modulation with mid-grey level as reference

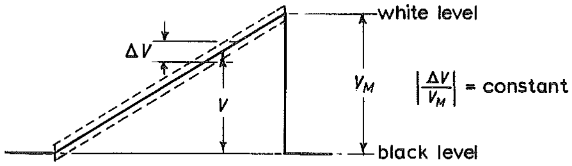

Fig. 2 - Effect of added interference on a sawtooth video signal

Broken lines in these figures represent limits of variation of video signal

signal by a further signal varying in amplitude in the same random manner during each line period. Some form of stored record of suitable random variations was therefore required since these variations had to be reproduced repetitively.

For this purpose, it was decided to make use of the random nature of the grain structure of a uniformly exposed piece of film. One possible method of making use of this grain structure would have been to place the film in a flying-spot scanner in which the field scan was disconnected, so that the same cross-section of the film would be scanned during each line period. However, this method had the disadvantage that, in order to prevent damaging the phosphor in the flying-spot tube, only a very small beam current could be used. This meant that the signal obtained from the scanner would have had a very poor signal-to-noise ratio.

In order to overcome this difficulty a film was produced on which an image of a narrow section of film grain was photographed in an elongated form.

The method of obtaining the film was as follows: a very 'grainy' piece of film was first obtained by making a high-gamma print of the grain structure of uniformly exposed Ilford H.P.S. film on Kodalith Ortho film. This print was then placed on a motor-driven carriage which was mounted in an enlarger. Also supported on the carriage, immediately above the print, was a slit allowing light to pass through only a very narrow strip of the print. By driving this carriage in a direction perpendicular to the length of the slit, an elongated image of the film grain immediately below the slit was obtained. A piece of fine-grain 35-mm positive film type 5302 was exposed to this image and the result is shown in Fig. 3. A repetitive signal could be obtained from this film by scanning it with a normal raster on the flying-spot tube.

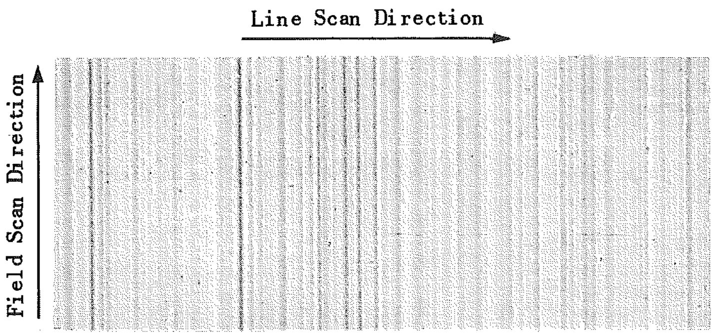

Fig. 3 - Enlarged photograph of part of film used to produce modulating signal

Owing to the high overall gamma of the photographic process, the variations in the optical transmission of the final film had to be kept reasonably small in order that they should be as symmetrical as possible about their mean value, but they could not be made too small as this would have resulted in a poor signal-to-noise ratio being obtained when the film was placed in a flying-spot scanner. In the film used the ratio of the peak-to-peak variation in the transmission to the mean value of the transmission was controlled by adjustment of the width of the slit, the ratio adopted in practice being about 1 : 4.

The signal obtained, when this film was placed in a flying-spot scanner, was equalized for high-frequency losses occurring in the photographic and scanning processes so that its frequency spectrum was flat from 0 to 3 Mc/s, as would be the case if the variations in the signal were perfectly random. The bandwidth of this signal was limited to 3 Mc/s and its amplitude controlled by a variable calibrated attenuator. A waveform photograph (see Fig. 4) of the equalized and bandwidth-limited signal, representing a sample 10 μs in duration, showed that the variations in amplitude about the mean were very similar in form to those occurring in a signal obtained from a white-noise generator also limited to a bandwidth of 3 Mc/s (see Fig. 5). In another test carried out to check the characteristics of the signal, the peak-to-peak magnitude of the variations in the signal, measured on an oscilloscope, was found to be 18 dB greater than their r.m.s. magnitude. This figure agrees well with similar measurements carried out on a purely random, bandwidth-limited, signal.

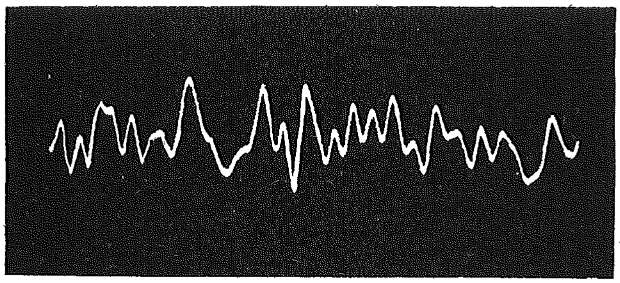

Fig. 4 - 10 μs sample of modulating signal

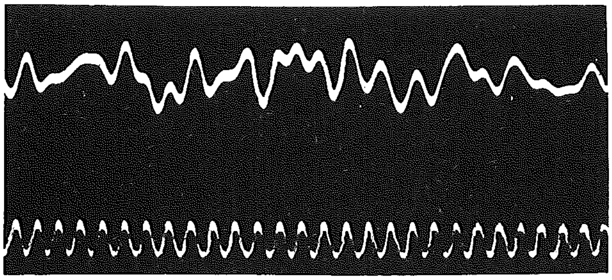

Fig. 5 - 10 μs sample of white noise signal limited in bandwidth to 3 Mc/s and 3 Mc/s timing signal

2.2. Measurement of Subjective Effect of Modulation

The signal described in Section 2.1. was applied to the grid of a second flying-spot scanning tube used to produce the picture signals for the subjective test. This provided an easy means of low-level modulation of these picture signals.

The two scanners used to provide the modulating signal and the video signals respectively were both driven by pulses from the same pulse generator, so that the resulting picture striations were rigidly locked to the displayed raster.

The modulated video signal was displayed on a 21 inch (53 cm) monitor and six observers, seated at between five and seven times the picture height from this monitor, were asked to assess the visibility of various levels of the interference according to the scale given in Table 1.

TABLE 1

Scale of Subjective Effect of Interference

SUBJECTIVE EFFECT OF INTERFERENCE	SCORE
Imperceptible	1
Just perceptible	2
Definitely perceptible but not disturbing	3
Somewhat objectionable	4
Definitely objectionable	5
Unusable	6

The tests were carried out using both stationary pictures from a slide scanner and moving pictures from a telecine machine. Two stationary pictures were used, these being Test Card 'C' and a pictorial scene which mainly consisted of detailed information and contained no large areas of uniform brightness. These two slides were chosen in order to assess the difference in the visibility of striations when using very different types of scene.

3. EXPERIMENTAL RESULTS

The results of the tests are shown in Fig. 6. The definition of modulation level used in these results is:

$$\text{Peak-to-peak modulation level} = 20 \log_{10} \left| \frac{\Delta V}{V} \right|$$

where ΔV is the peak-to-peak variation in signal magnitude caused by the modulating signal when used to modulate a video signal of amplitude V.

It can be seen from Fig. 6 that, when the interference is definitely visible, the level of modulation causing a given visibility of interference is about 3 to 6 dB greater for stationary pictures than for moving pictures. The modulation level required for interference at the threshold of perception, however, is about -42 dB for both moving and stationary pictures.

4. EFFECT OF ADDED INTERFERENCE AND MODULATING INTERFERENCE WITH MID-GREY LEVEL AS REFERENCE

Since the tests relating to a simulated modulating signal, described in Sections 2 and 3, were completed, work has been carried out on the design of switches and storage devices. It has been found that variations in the characteristics of the particular type of switch and storage device investigated cause perturbations of the output signal which differ in two ways from those investigated in the subjective tests

First, the modulation reference level of the perturbations may be mid-grey level, and not black level as had been assumed; this difference is illustrated in Fig. 1. It will be convenient to define the abbreviative symbols:-

$$\alpha_{mb} = |\Delta V/V|$$

$$\alpha_{mg} = |\Delta V/(V - \tfrac{1}{2}V_M)|$$

$$\alpha_a = |\Delta V/V_M|$$

where ΔV, V and V_m are specified as shown in Figs. 1(a) and 1(b).

For modulation with black level as reference Fig. 1(a):

α_{mb} is constant at all video levels

and peak-to-peak modulation level is defined as 20 $\log_{10} \alpha_{mb}$

For modulation with mid-grey level as reference Fig. 1(b):

α_{mg} is constant at all video levels

and peak-to-peak modulation level is defined as 20 $\log_{10} \alpha_{mg}$

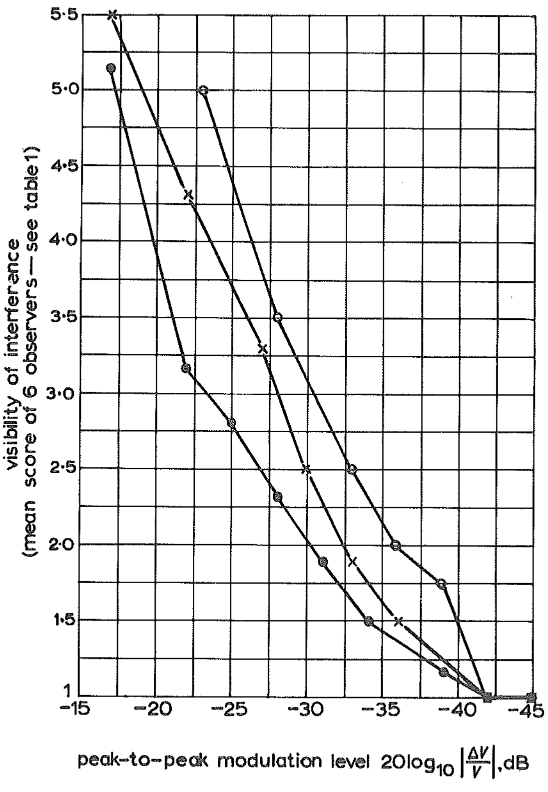

Fig. 6 - Visibility of interference due to variation of switch transfer efficiencies

—o— Moving pictures
—x— Test Card 'C' slide
—●— V.I.P. Studio slide

Secondly, in addition to the variations which cause modulation of the video signal, the switches and storage devices also vary in a manner which causes a perturbing signal of the same general form as the modulating signal to be added to the video signal. The effect of this added signal on a sawtooth video waveform is shown in Fig. 2. For this type of perturbation α_a is constant at all video levels.

The subjective effects of both modulation using mid-grey level as reference

and the addition of a perturbing signal can be deduced, however, from the results of the tests on modulation with black level as reference; the calculations involved are given in an Appendix to this report. These calculations give the values of α_{mb}, α_{mg} and α_{a} required to maintain constant visibility of a perturbing signal of magnitude ΔV as the video signal level V is varied. Curves illustrating these variations, for the experimental conditions used in the tests described in this report, are given in Fig. 7. In this figure the horizontal axis has been calibrated in terms of the luminance of the display corresponding to the level V of the video signal, the display being adjusted to have a luminance of 20 ft-L (215 asb) for a video signal level of V_M.

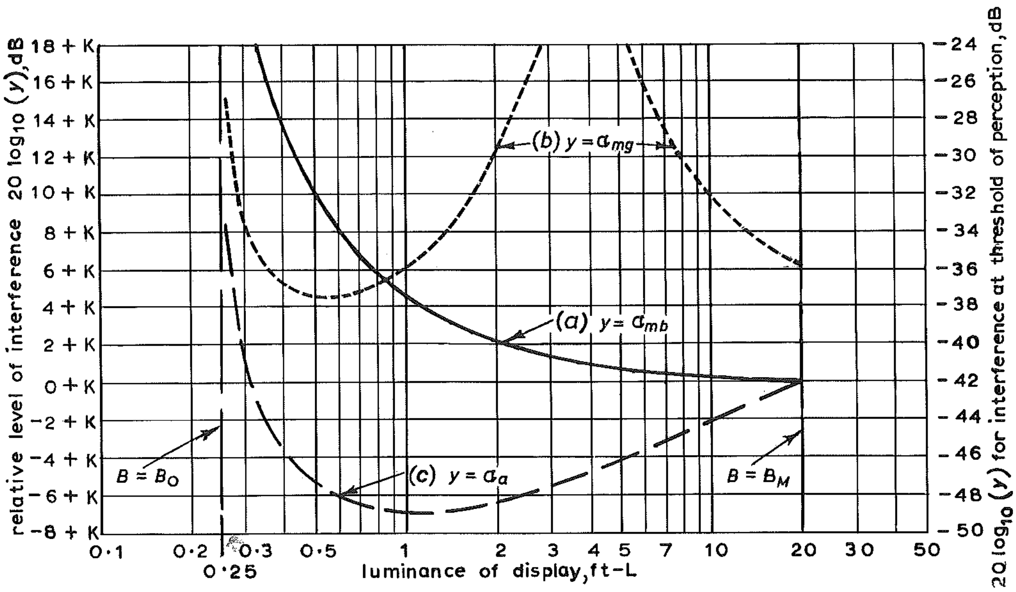

Fig. 7 - Relative level of interfering signal causing constant visibility of interference on a television display plotted against luminance of display

(a) Modulating interference with black level as reference
(b) Modulating interference with mid-grey level as reference
(c) Added interference
K = constant for given visibility of interference

From theoretical considerations, the left-hand vertical axis on Fig. 7 can only be calibrated in terms of those relative values of α_{mb}, α_{mg} and α_{a} which correspond to a constant visibility of perturbations. However, by making use of the results of the subjective tests described in this report, the right-hand vertical axis can be calibrated in terms of those absolute values of α_{mb}, α_{mg} and α_{a} which correspond to a given visibility of perturbation; the values obtained in this way for the threshold level of perturbing signal are given along the right-hand vertical axis on Fig. 7.

If the perturbing modulation caused by a given set of switches and storage devices has black level as reference, α_{mb} is constant for all luminances of the display. The perturbations resulting from this type of modulation are, therefore,

most visible when the luminance of the display is equal to the luminance corresponding to the minimum value of α_{mb} shown in Fig. 7, curve (a); i.e. a luminance of 20 ft-L (215 asb). It was found from the subjective tests that 20 log α_{mb} = -42 dB if the resulting perturbations were to be at the threshold of perception (see Fig. 6). The right-hand vertical scale on Fig. 7 has therefore been adjusted so that, for curve (a), 20 $\log_{10} \alpha_{mb}$ = -42 dB at a luminance of 20 ft-L (215 asb).

When the modulation caused by a given set of switches and storage devices has mid-grey level as reference, α_{mg} is constant for all luminances of the display. The perturbations resulting from this type of modulation are therefore most visible when the luminance of the display is equal to the luminance corresponding to the minimum value of α_{mg} in Fig. 7, curve (b); i.e. a luminance of 0·5 ft-L (5·4 asb). It can be seen from curve (b) that perturbations resulting from modulation with mid-grey as reference is imperceptible if the peak-to-peak modulation level given by 20 log α_{mg} is less than -37·5 dB.

Finally, the added perturbing signal resulting from a given set of switches and storage devices gives rise to a constant value of α_a at all luminances of the display. These added perturbations are, therefore, most visible when the luminance of the display is equal to the luminance corresponding to the minimum value of α_a in Fig. 7, curve (c); i.e. luminance of 1·0 ft-L (10·7 asb). It can be seen from curve (c) that the added perturbations will be imperceptible if 20 log $\alpha_a < -49$ dB; i.e. if the added perturbing signal is less than -49 dB relative to the black-to-white magnitude of the wanted video signal.

5. CONCLUSIONS

If variations in the transfer efficiencies of the switches and storage devices in a line-store standards converter cause the converted video signal to be modulated about black level as a reference, the peak-to-peak modulation level, 20 $\log_{10} \alpha_{mb}$, should not be greater than -42 dB if the resulting vertical picture striations are to be imperceptible on either moving or stationary pictures.

If the modulation occurs about mid-grey level as a reference, the peak-to-peak modulation level, 20 $\log_{10} \alpha_{mg}$, should not be greater than -37·5 dB if the resulting vertical picture striations are to be imperceptible on either moving or stationary pictures.

If variations in the switches and storage devices cause a perturbing signal to be added equally at all video levels, then the peak-to-peak variations in the video signal should not have a level greater than -49 dB relative to the black-to-white magnitude of the video signal if the resulting vertical picture striations are to be imperceptible on either moving or stationary pictures.

6. ACKNOWLEDGMENTS

The writer of this report would like to acknowledge the help of his colleagues, for their work in preparing the film from which the modulating signal was obtained, in particular Mr. R. Sims.

Fig. 5 was reproduced from a Designs Department Technical Memorandum.[2]

7. REFERENCES

1. 'An Outline of Synchronous Standards Conversion Using a Delay-Line Interpolator', Research Department Report No. T-096, Serial No. 1962/31.

2. 'Some Theoretical and Experimental Characteristics of Random Noise', Designs Department Technical Memorandum, Serial No. 7.10(56).

3. 'Line-Store Standards Conversion : Subjective Effect of Unconverted Components', Research Department Report No. T-113, Serial No. 1963/41.

APPENDIX

Relative Subjective Effects of Added Interference and Modulating Interference on a Television Display

This Appendix describes a method of deducing, from the results of the tests on perturbations due to modulation with black level as reference, the subjective effects of perturbations due both to modulation with mid-grey as reference and to the addition of a perturbing signal. The effects of these three types of perturbation, when applied to a sawtooth video signal, are illustrated in Figs. 1 and 2. In these figures, ΔV represents the peak-to-peak magnitude of the variations of a video signal of level V which result from variations in the transfer characteristics of the switches and storage devices in a line-store standards converter. Considering, first, variations in the characteristics of a set of switches and storage devices which cause the video signal to be modulated with black level as reference, we note that α_{mb} is constant for all video levels. Secondly, if the variations in the characteristics cause the video signal to be modulated with mid-grey level as reference, α_{mg} is constant for all video levels. Finally, if the variations result in the addition of a perturbing signal at all video levels, α_a is constant.

The calculations for determining the relative subjective effects of the three different types of perturbation are based on two assumptions;[3] these are:

(i) It is assumed that the luminance B of the display tube used in the tests is related to the applied signal voltage V by the equation:

$$B - B_0 = AV^{\gamma} \tag{1}$$

where B_0 = luminance of an unexcited area of the display caused by ambient illumination, and

A and γ are constants.

If the maximum luminance B_M results from an applied signal of magnitude V_M, then

$$A = \frac{B_M - B_0}{V_M^{\gamma}} \tag{2}$$

Therefore from equations (1) and (2):

$$\frac{B - B_0}{B_M - B_0} = \left(\frac{V}{V_M}\right)^{\gamma} \tag{3}$$

(ii) It is assumed that, under the adaption conditions of the eye which exist when an average television display is being viewed, the difference ΔS in the sensation S caused by light from two adjacent areas that differ in luminance by a small amount ΔB is given by:

$$\Delta S = \frac{k\Delta B}{B + B_1} \tag{4}$$

where B is the luminance of the brighter of the two areas

B_1 is a constant for given viewing conditions, being dependent on the amount of glare light received by the eye from the field surrounding the two areas.

k is a constant relating to two areas of a given shape subtending a given angle at the fovea of the eye.

If the difference in luminance ΔB between two adjacent areas on a television display is caused by a difference ΔV in the corresponding signal levels then, from equations (3) and (4), the following three relationships can be deduced:

$$\alpha_{mb} \simeq \frac{\Delta S}{k\gamma} \; \frac{B + B_1}{B - B_0} \tag{5}$$

$$\alpha_{mg} \simeq \frac{\Delta S}{k\gamma} \left(\frac{B + B_1}{B - B_0}\right) . \left| 1 - \tfrac{1}{2}\left(\frac{B_M - B_0}{B - B_0}\right)^{1/\gamma} \right|^{-1} \tag{6}$$

$$\alpha_{a} \simeq \frac{\Delta S}{k\gamma} \left(\frac{B + B_1}{B - B_0}\right) . \left(\frac{B - B_0}{B_M - B_0}\right)^{1/\gamma} \tag{7}$$

(Approximations are involved because $\Delta B/\Delta V$ has been taken as being equal to dB/dV.)

In equations (5), (6) and (7), ΔS can be taken as representing the visibility of the perturbation caused by a signal of magnitude ΔV in an area having a luminance B.

Considering modulation with black level as reference, the peak-to-peak modulation level is equal to 20 $\log_{10} \alpha_{mb}$; equation (5) can therefore be used to obtain a curve showing the variation in the peak-to-peak modulation level required to produce a given visibility of perturbation - i.e. a given value of ΔS - at various luminances of the display (see Fig. 7 curve (a)).

For this curve:

$$20 \log_{10} y = 20 \log_{10}\left(\frac{B + B_1}{B - B_0}\right) + K$$

where $y = \alpha_{mb}$

and $K = 20 \log_{10}\left(\frac{\Delta S}{\gamma k}\right)$

Curve (a), and also curves (b) and (c), have been plotted for $\gamma = 2{\cdot}5$, $B_0 = 0{\cdot}25$ ft-L ($2{\cdot}7$ asb), $B_1 = 0{\cdot}3$ ft-L ($3{\cdot}2$ asb), $B_M = 20$ ft-L (215 asb), these being the values applicable to the tests described in this report.

Since, when the perturbing modulation is referred to black level, a given set of switches and storage devices are characterized by a constant value of α_{mb} at all brightness levels, the perturbations will be most visible when the luminance of the display is equal to the luminance corresponding to the minimum value of α_{mb} in curve (a); i.e. at a luminance of 20 ft-L (215 asb).

Similarly, considering modulation with mid-grey level as reference, for which the peak-to-peak modulation level is equal to 20 log α_{mg}, equation (6) can be used to obtain a curve showing the variation required to produce a given visibility of perturbation at various luminances of the display (see Fig. 7 curve (b)).

For this curve:

$$20\ \log_{10} y = 20\left\{\log_{10}\left(\frac{B + B_1}{B - B_0}\right) - \log_{10}\left|1 - \tfrac{1}{2}\left(\frac{B_M - B_0}{B - B_0}\right)^{1/\gamma}\right|\right\} + \mathrm{K}$$

where $y = \alpha_{mg}$

and $\mathrm{K} = 20\ \log_{10}\left(\dfrac{\Delta S}{\gamma \mathrm{K}}\right)$

For a given set of switches and storage devices, when the perturbing modulation obtained is referred to mid-grey level, the resulting interference will be most visible when the luminance of the display is equal to the luminance corresponding to the minimum value of α_{mg} on curve (b); i.e. at a luminance of 0·5 ft-L (5·4 asb).

Finally, equation (7) can be used to obtain a curve showing the variation in the magnitude of an added signal (expressed as a fraction of the black-to-white magnitude of the video signal) which is required to produce a given visibility of perturbation at various luminances of the display (see Fig. 7 curve (c)). For this curve:

$$20\ \log_{10} y = 20\left\{\log_{10}\left(\frac{B + B_1}{B - B_0}\right) + \frac{1}{\gamma}\log_{10}\left(\frac{B - B_0}{B_M - B_0}\right)\right\} + \mathrm{K}$$

where $y = \alpha_a$

and $\mathrm{K} = 20\ \log_{10}\left(\dfrac{\Delta S}{\gamma \mathrm{K}}\right)$

For an added perturbing signal the ratio α_a is constant at all brightness levels, and therefore the resulting perturbation will be most visible when the luminance of the display is equal to the luminance corresponding to the minimum value of α_a on curve (c); i.e. at a luminance of 1·0 ft-L (10·7 asb).

By making use of the results of the tests described in this report, the vertical axis on Fig. 7 can be calibrated in terms of the level of perturbing signal having a particular visibility on a display. For example, from the subjective tests it was found that:

$$20\ \log_{10} \alpha_{mb} \leqslant -\ 42\ \mathrm{dB}$$

corresponds to the condition that the modulation referred to black level has no

perceptible effect in those areas of the display where the interference could be expected to be most visible, i.e. in those areas of the display having a luminance of 20 ft-L (215 asb).

Since all three curves of Fig. 7 refer to a constant visibility of the perturbations, and since the forms of both the modulating signal and the added signal are similar, the threshold values of y both for the case of modulation referred to mid-grey level and for that of an added perturbing signal may be derived from the threshold values of y for modulation referred to black level. If the modulation with mid-grey level as reference is to be imperceptible at all brightness levels, then from Fig. 7 curve (b):

$$20 \log_{10} \alpha_{mg} \leqslant -37{\cdot}5 \text{ dB}$$

If an interfering signal, which is added equally to all video levels, is to be imperceptible at all brightness levels, then from curve (c):

$$20 \log_{10} \alpha_{a} \leqslant -49 \text{ dB.}$$

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